Corrosion Fatigue in Offshore Structures

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1 Introduction

Offshore wind energy industry around globe is expanding rapidly in the recent decade to face challenges on the tremendous demand of eco-friendly electricity [1]. Steel welded substructures for supporting wind turbines are usually subjected to a complex dynamic spectrum of fatigue loads due to wind, wave and current. Fatigue failure can happen when external load that is much lower than material yield strength is applied for a long period of time. At the same time, they are immerged in or exposed to corrosive seawater. The corrosive environment plays an important role during the metal fatigue process, as corrosion accelerates aging rate of material and local high stress concentration at fatigue crack tip reinforce chemical reaction, the interaction of fatigue and environmental degradation significantly reduce life span of the structure and increase cost of installation and maintenance. Therefore, the investigation of combined damage from fatigue and corrosion mechanism is needed for improving understanding of corrosion fatigue phenomenon in offshore structures and advanced numerical tool of simulation and life prediction of corrosion fatigue is required to help engineers design more durable and lightweight structures, so to decrease the cost. This extended abstract gives an overview of corrosion fatigue modelling and methods used.

2 Corrosion effect on fatigue

Corrosion fatigue presents difficulties at the preliminary design stage of offshore structures. The fatigue limit (or fatigue strength or endurance limit), the stress value under which is used in fatigue resistance design and considered as infinite life for material, is eliminated from SN curve in corrosion fatigue scenario, as illustrated in the left diagram of Figure 1.

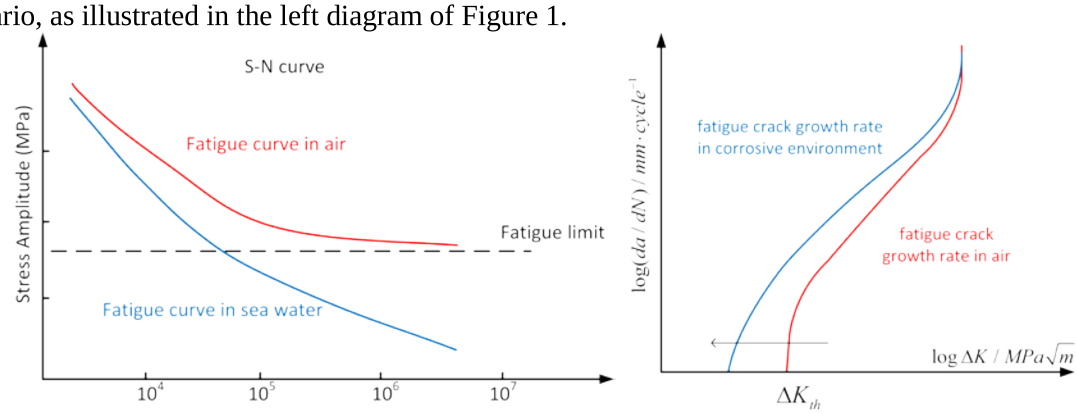

Figure 1 Schematic diagrams of corrosion effect on fatigue properties

Additionally, corrosion effect reduces the fatigue crack growth threshold and accelerates crack propagation rate, it means that crack can advance in lower stress range and grow much fast than fatigue crack in the air under the same load condition, as shown in the right diagram of Figure 1. This paper gives an overview on corrosion fatigue simulation and lifetime prediction.

3 Methodologies

Similar to fatigue phenomenon in the air, corrosion fatigue consists of two main stages, namely crack initiation and crack propagation. Technically, two stages can be investigated separately and the total life for corrosion fatigue of a defect-free component can be summed those two stages.

The initiation model of corrosion fatigue proposed is based on non-linear continuum damage mechanics (CDM) [2], by discretizing fatigue damage into different corrosion conditions. The corrosion effect is represented by a time dependent reduction of the fatigue property within CDM accumulation model. Notably, fatigue limit of engineering metals (steels, aluminium and magnesium alloy) significantly decrease when immersed in a certain corrosive environment for different time span. It can be translated into SN curves obtained from pre-corroded specimens. A time-dependent interpolation between SN curves in absence and presence of different degrees of corrosion then allows to describe the coupled effect of corrosion and fatigue. The reduction of fatigue limit due to corrosion is expressed in terms of the associated increase in roughness. The lifetime prediction under a certain stress range can be estimated by damage reaching the critical value of the material. Load sequence effect is successfully included because of nonlinearity of the damage accumulation.

For the propagation model, a numerical framework [3] is developed based on linear elastic fracture mechanics (LEFM) and extended finite element method (XFEM) to simulate how an arbitrary three-dimensional fatigue crack propagates. Resulting in much less computational effort, XFEM calculates stress intensity factors without very fine mesh in the vicinity of crack. Those information is used in an iterative loop, cooperating with crack propagation rate for corrosion fatigue scenario, to determine crack advancing increment and growth direction, until unstable crack growth or crack arrest criterion is reached. Multiaxial loading and variable amplitude effect for crack propagation are considered by implementing effective stress intensity factor of three crack opening modes and plastic zone models. Propagation life prediction is achieved by integrating stress intensity factors in terms of propagation law.

4 Conclusion

Modelling for corrosion fatigue initiation and propagation is introduced concisely and numerical tools are developed based on CDM and LEFM. This work can benefit to durability design of offshore structure as an auxiliary means.

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